Laser-Based Measurement of Thermal Conductivity

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In nuclear fuel thermal conductivity is related to energy conversion efficiency as well as reactor safety and is arguably one of the most important material properties. It is well known that thermal conductivity of nuclear fuel degrades due changes in material microstructure brought about by neutron irradiation. Furthermore the character of the microstructure depends strongly on the local environment and can change drastically over a few millimeters from the fuel element center to the fuel element rim. Thus to validate and benchmark computational material science models it is necessary to develop new spatially resolved tools that can accurately measure thermal conductivity on length scales commensurate with microstructure heterogeneity. Laser-based methods have emerged as a leading candidate for making precise, spatially localized thermal transport measurements. In general these methods use a pump laser for transient heating and a probe laser to measure the temporal evolution of the resulting temperature field. Because laser-based methods measure transient temperature changes, they are limited to measuring some combination of conductivity, density and specific heat. Typically researchers extract the thermal conductivity from these measurements by performing an additional experiment to measure specific heat. This requires destructively removing a small volume of the test sample to be placed in a calorimeter. For highly radioactive material this approach raises serious waste management issues. This work detailed in this manuscript involves the development of a laser-based technique to remotely measure the thermal conductivity of nuclear fuel on a micron length scale. Our approach involves using a hybrid frequency/spatial domain approaches to measure the thermal effusivity, e, and thermal diffusivity, D. The thermal conductivity, $k=(e^2D)^{1/2}$, can be extracted from these measurements.